FEAP

**FACILITIES ENGINEERING
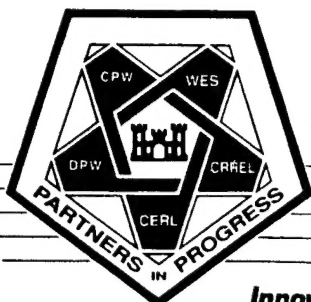APPLICATIONS PROGRAM**

**TECHNICAL
REPORT**

Demonstration of Remote Monitoring Technology for Cathodic Protection Systems: Phase II

by
Vicki L. Van Blaricum, Jack T. Flood, Michael J. Szeliga,
and James B. Bushman
U.S. Army Construction Engineering Research Laboratories
Champaign, IL 61826-9005

19981007 011

Approved for Public Release; Distribution is Unlimited.

U.S. Army Center Public Works
Alexandria, VA 22315-3862

Innovative Ideas for the Operation, Maintenance, & Repair of Army Facilities

DTIC QUALITY INSPECTED 3

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products. The findings of this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

CECER-TR-I

Subject: DTIC
Accession of Cerl Technical Report

Defense Technical Information Center
8725 John J. Kingman Rd., STE 0944
Fort Belvoir, VA 22060-6218

Enclosed are 2 copies of the CERL Technical Report cited on the accompanying
DTIC Form 50.

SHIRLEY BARNES
Publications

USER EVALUATION OF REPORT

REFERENCE: FEAP Technical Report 98/82, *Demonstration of Remote Monitoring Technology for Cathodic Protection Systems: Phase II*

Please take a few minutes to answer the questions below, tear out this sheet, and return it to USACERL. As user of this report, your customer comments will provide USACERL with information essential for improving future reports.

1. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which report will be used.)

_____

_____

_____

2. How, specifically, is the report being used? (Information source, design data or procedure, management procedure, source of ideas, etc.)

_____

_____

3. Has the information in this report led to any quantitative savings as far as manhours/contract dollars saved, operating costs avoided, efficiencies achieved, etc.? If so, please elaborate.

_____

_____

4. What is your evaluation of this report in the following areas?

   a. Presentation: _____

   b. Completeness: _____

   c. Easy to Understand: _____

   d. Easy to Implement: _____

   e. Adequate Reference Material: _____

   f. Relates to Area of Interest: _____

   g. Did the report meet your expectations? _____

   h. Does the report raise unanswered questions? _____

i. General Comments. (Indicate what you think should be changed to make this report and future reports of this type more responsive to your needs, more usable, improve readability, etc.)

_____

_____

_____

_____

_____

_____

5. If you would like to be contacted by the personnel who prepared this report to raise specific questions or discuss the topic, please fill in the following information.

Name: _____

Telephone Number: _____

Organization Address: _____

_____

_____

6. Please mail the completed form to:

Department of the Army
CONSTRUCTION ENGINEERING RESEARCH LABORATORIES
ATTN: CECER-TR-I
P.O. Box 9005
Champaign, IL 61826-9005

REPORT DOCUMENTATION PAGE

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE May 1998	3. REPORT TYPE AND DATES COVERED Final

4. TITLE AND SUBTITLE Demonstration of Remote Monitoring Technology for Cathodic Protection Systems: Phase II	5. FUNDING NUMBERS FEAP F17

6. AUTHOR(S)
Vicki L. Van Blaricum, Jack T. Flood, Michael J. Szeliga, and James B. Bushman

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Construction Engineering Research Laboratories (USACERL) P.O. Box 9005 Champaign, IL 61826-9005	8. PERFORMING ORGANIZATION REPORT NUMBER FEAP TR 98/82

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Center for Public Works ATTN: CECPW-ES 7701 Telegraph Road Alexandria, VA 22310-3862	10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Cathodic protection (CP) is used to prevent corrosion on many buried and submerged metallic structures such as underground pipes and tanks. Periodic testing is required to ensure proper CP system operation, but many Directorates of Public Works (DPWs) do not have sufficient resources to conduct such tests regularly.

Several companies have begun manufacturing remote monitoring units (RMUs) for CP systems. The technology allows personnel to monitor multiple CP systems from a central location so problems can be detected and repaired immediately. RMUs from three manufacturers were evaluated during Phase I of this study (FEAP TR 97/76) to determine their effectiveness. Only one of them performed successfully. During Phase II, RMUs from two additional manufacturers were evaluated. Results showed that both of the systems from Phase II performed successfully and are suitable for use at Army installations.

14. SUBJECT TERMS Cathodic Protection FEAP remote monitoring units (RMUs) corrosion control	15. NUMBER OF PAGES 47
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT SAR

NSN 7540-01-280-5500

Foreword

Contents

List of Tables and Figures

1 Introduction

Background

Metallic structures buried in soil or submerged in water tend to corrode. Corrosion of storage tanks and piping systems can result in premature failures, costly losses of the substance being conveyed or stored, leakage of hazardous materials into the environment, diminished system reliability, and high life-cycle costs. Cathodic protection (CP) is required by regulation and Army policy on many of these structures to prevent corrosion. CP systems must be periodically evaluated to ensure that they are providing adequate, continuous corrosion protection. The evaluation is typically done by field engineers or technicians who travel to each rectifier and test station and conduct a series of measurements with hand-held meters. Lack of resources has made it difficult for Army Directorates of Public Works (DPWs) to perform CP testing on a regular basis. Consequently, many CP system malfunctions may remain undetected until the structure that was supposed to be protected corrodes and leaks.

Several companies manufacture remote monitoring units (RMUs) designed specifically for evaluating impressed current CP systems. These units can monitor multiple CP systems from a single IBM-compatible computer.* This *master computer* can be located anywhere on or off an installation—even thousands of miles away from the rectifiers and test sites. RMUs minimize the amount of time required for CP system evaluation because personnel do not need to visit the site unless a CP problem is detected. RMUs therefore make it easier for Army installations to establish a regular CP testing program, and they make it possible to detect and repair CP system malfunctions quickly, before they allow corrosion-related failures to occur.

---

* In this report, "IBM-compatible" refers to personal computers capable of running the Microsoft Disk Operating System (MS-DOS) and Microsoft Windows 3.1 or later.

As part of its ongoing research and development in the area of corrosion prevention, the U.S. Army Construction Engineering Research Laboratories (USACERL) conducted a two-phase demonstration of remote CP monitoring technology under the Army's Facilities Engineering Applications Program (FEAP).

Phase I of the demonstration was conducted during Fiscal Years (FY) 1995-1996. RMUs from three manufacturers were evaluated over an 8-month test period. The evaluation showed that only one of the RMUs tested, the MC Miller DAX, was fully functional, operational, accurate, and reliable throughout the demonstration (Van Blaricum et al. 1997).

Several additional manufacturers introduced new RMUs onto the market too late to be evaluated during Phase I. Because it is desirable to give Army installations a choice of vendors, it was decided to conduct a second phase of the demonstration to evaluate additional CP RMUs.

Objective

The objective of this study was to evaluate the field performance of additional commercially available impressed current CP RMUs for use on Army installations.

Approach

1. A market survey was conducted in early FY97 to identify commercially available CP RMUs that had entered the market since the Phase I demonstration. The two candidate systems that best met Army requirements were selected for testing.

2. One RMU from each of the two selected manufacturers was installed at a USACERL outdoor CP test facility. CP system performance was measured daily using the RMUs. The same measurements were also taken on-site daily using hand-held meters and typical CP field-test procedures. The results of the two measurement methods were compared to determine the accuracy of the RMU measurements.

3. One RMU from each of the two manufacturers was installed on the CP system that protects the underground high-temperature hot water distribution

system at Fort Drum, NY. Readings were taken remotely on a weekly basis. RMU readings were compared with manual readings at installation time to determine the accuracy of the RMU measurements.

4. In addition to the field measurements, units were compared in terms of other features such as ease of installation, software capabilities, and quality of system documentation. The results of these evaluations were used along with the field measurement results to provide a comprehensive evaluation of the two units.

Scope

This study should not be considered all-inclusive. It includes only the CP RMUs that met specific criteria at the time of the manufacturer survey in early 1997. These requirements are listed in Chapter 2. There were systems available at the time of the survey that did not fully meet these requirements, but may meet them now. Furthermore, other manufacturers may have introduced new systems onto the market since the time of the survey.

The hardware that was tested was procured between February and May 1997 and can be assumed to be representative of the hardware that was available from the two manufacturers at that point in time. Some of the manufacturers may have updated or improved their hardware since that time, but these updates were not addressed in this study. Any software updates provided by the manufacturers were implemented throughout the study period.

Mode of Technology Transfer

The results of this work are being published in a FEAP User Guide and a FEAP Ad Flyer to assist installations in procuring the technology. In addition, specifications for CP RMUs should be incorporated into Corps of Engineers Guide Specification 16642, *Cathodic Protection System, Impressed Current*.

2 Market Survey and RMU Features

Basics of CP Remote Monitoring

CP RMUs can be used to measure rectifier output voltage and current, rectifier input voltage, and structure-to-soil potentials. Many of the RMUs can be configured to measure instant-off potentials (IOPs). These tests are described in detail in the Phase I report (FEAP TR 97/76) (Van Blaricum et al. 1997).

Each RMU is typically installed near a CP rectifier. A permanent copper-copper sulfate reference electrode is buried near the pipe at each monitoring location and its lead wire is routed to the RMU. The terminals of the RMU are connected to the CP equipment so the rectifier output voltage, rectifier output current, rectifier input voltage, and pipe-to-soil potential (versus the permanent electrode) can be measured. A telephone line is connected to each RMU to enable communication with the central computer. Connection details are specific to each manufacturer.

Market Survey

The market survey of commercially available CP RMUs for this phase of the project was conducted in early FY97. The systems were evaluated against the following criteria:

1. Units must currently be ready for production and testing.
2. Units must be manufactured in the United States.
3. Units must be able to monitor a typical CP system without extensive rewiring, configuring, or programming by the user.
4. Units must be competitively priced.

Units that did not meet the criteria were eliminated from consideration. The units that were chosen for this phase of the evaluation were:

1. CPM II Remote Monitoring System (Metretek)
2. PAC3 Remote Monitoring System (JA Electronics)

3. Lynx 2000 Monitoring System (CPS Technologies).

Unfortunately, the manufacturer of the Lynx 2000 system was unable to provide RMUs in a timely manner and the units arrived too late to be included in the tests. This was reportedly due to a corporate restructuring of CPS Technologies in the first half of 1997. Therefore, only the CPM II and the PAC3 were tested.

In addition, the MC Miller DAX unit from Phase 1 was still in place at Fort Drum, so it was included in the field-tests there.

RMU Specifications

The ordering specifications for the RMUs were based on typical Army installation requirements. They were tailored to the Fort Drum and USACERL test sites as noted in the descriptions below. The following specifications were provided to each of the selected manufacturers:

1. RMUs shall be able to perform the following measurements. The RMU shall contain a total of 4 channels.

- Structure-to-soil "on" and "instant-off" potentials from 0 to –4 volts with a resolution of ±5 mV using existing permanently installed reference electrodes at each test site. One channel shall be capable of performing this measurement.
- Rectifier direct current (DC) voltage in the range of 0 to 27 volts DC for one unit (specific requirement for USACERL test site) and 0 to 60 volts DC for one unit (specific requirement for Fort Drum test site), with a resolution of ± 100 mV. One channel shall be capable of performing this measurement.
- Rectifier DC current in the range of 0 to 15 amperes DC (requirement for both the USACERL and Fort Drum test sites). Current measurements shall be obtained by conducting a voltage measurement across the rectifier shunt and using Ohm's Law to calculate the current. The rectifier shunt is rated at 50 mV / 20 A. The voltage measurement across the rectifier shunt shall have a resolution of ± 0.1 mV. One channel shall be capable of performing this measurement.
- Rectifier alternating current (AC) voltages of 120 volts AC for one unit (specific requirement for USACERL test site), and 240 volts AC for one unit (specific requirement for Fort Drum test site) with a resolution of ± 1 V. One channel shall be capable of performing this measurement.

2. Units shall have both input and output surge protection on each data channel, the power supply, and the telephone line.

3. Units shall have full differential channels when possible.

4. Units shall have a battery backup capable of providing power for at least 300 one-minute phone calls in the event of an AC power failure.

5. Units shall be preconfigured to operate from a 120 VAC power supply for one unit (specific requirement for USACERL test site) and a 240 VAC power supply for one unit (specific requirement for Fort Drum test site).

6. The manufacturer shall supply the external relay control or other means necessary for the units to measure IOPs by interrupting current. If possible, units should be equipped to interrupt several units simultaneously (synchronized interrupt). This relay shall meet the following requirements:

- UL listed and CSA certified heavy duty power relay
- design for high-inrush current applications
- life expectancy of 100,000 operations at full load
- silver-cadmium oxide contacts
- floating movable contact carrier
- operating temperature range of -55 °C to 80 °C (-67 °F to 176 °F)
- capable of being used with a rectifier with a maximum DC output of 0 to 27 volts DC for one unit (requirement for USACERL test site) and 0 to 60 volts DC for one unit (requirement for Fort Drum test site).

7. Units shall have a waterproof quick-disconnect-type channel interface when possible.

8. Units shall possess an auto-ranging capability with software-selectable voltage ranges when possible.

9. The manufacturer shall include all software required to operate and monitor the RMU.

10. Units shall be able to store user-specified upper and lower limits for each channel and should have the capability to "auto call" and identify system ID and error type to personal computer (PC) systems monitoring the station when an out-of-limits condition is measured.

11. Units shall have the capability to take readings periodically at user-specified time intervals when possible.

RMU Features

Tables 1 and 2 list the features of the CPM II and the PAC3 remote monitoring systems.

Table 1. Metretek CPM II features.

Characteristic	Description	Comments
Circuitry (100% Solid State)	Yes	
Component Grade	Industrial	
No. of Data Channels	7	8th channel for kilowatt hours
Call up addressable	Yes	
Data channel type (full diff. or common)	Differential	
Standard DC Voltage Ranges	100m,2,3,50V	Chnl 2-4: 0-100mv shunt, 2V low side input; Chnl 5-6: 50 V low side, 3V structure to pipe; Chnl 7: 3V Structure to pipe or 50 V low side or site temp.
Standard AC Voltage Ranges	250 V	Channel 1
Input Impedance	188K to 10G	
Autoranging	No	Jumper Selectable
Software Selectable Ranges	No	(on or off selectable)
Hardware Selectable ranges	Yes	
CP Equipment independent	Yes	
Country of Manufacture	USA	
Power Requirements	6Vdc	Via 6vdc, 400mA adapter included
Battery Backup	Yes	About 1 yr using either alkaline or lithium batteries
Power Supply Lightning Protection	Yes	
Phone Line Lightning Protection	Yes	Standard
Data channel lightning protection	Yes	
Base Unit Cost*	$1880	One proprietary modem and software package required per master computer ($2974 extra)
Data Memory	1500 readings	1500 measurements per input channel
Stored Data Nonvolatile	No	
Program storage	EPROM	
Type of Communication (Radio, phone)	Modem	Cellular available.
Modem included	Yes	

* Includes the RMU and relay (for current interruption) assembled in a weatherproof enclosure.

Characteristic	Description	Comments
Hayes Compatible	No	
Modem rate	300-2400 bps	
Error checking Protocol	V.22	1200 and 2400 only
Data transmission	Full Duplex	At 300, 1200, 2400 bps using Bell 212A, CCITT v.22 bis
Auto call	Yes	Originates or answers data calls
Relay control for Instant-off potential	Yes	Two independent on/off outputs w/ logic level or optoisolated interface. Capable of syncing multiple rectifier interruptions in <2 ms w/o GPS
Case	Yes	NEMA 4 rated, 16 gauge steel. Optional Enclosures Available
Software base	Windows	
Software flexibility	Yes	Easy to use Windows-based control, communications, & data management software.
OLE 2.0 Compliance	-	
ODBE Compliance	-	
Graphical Data Analysis	Yes	
Installation/Removal (wiring)	Screw	
Special Installation (mounting)	None	Prefabricated stations available as option (Cellular and/or Solar)
Temp. rating	(-30 to 70) °C	
Humidity rating	10 to 98%	Noncondensing
UL listing	No	
Warranty	1 year	From date of shipment

Table 2. JA Electronics PAC3 features.

Characteristic	Description	Comments
Circuitry (100% Solid State)	Yes	
Component Grade	Industrial	
No. of Data Channels	4	3 digital
Call up addressable	Yes	
Data channel type (full diff. or common)	Common	
Standard DC Voltage Ranges	50m to 100 V	
Standard AC Voltage Ranges	-	
Input Impedance	> 1 M	
Autoranging	Yes	
Software Selectable Ranges	Yes	Calibrated at time of shipment
Hardware Selectable ranges	No	Calibrated at time of shipment
CP Equipment independent	Yes	
Country of Manufacture	USA	
Power Requirements	7 to 16V	120 to 10 VAC or 120 to 12 VAC step down

Characteristic	Description	Comments
		transformer is adequate.
Battery Backup	Yes	
Power Supply Lightning Protection	Yes	
Phone Line Lightning Protection	Yes	
Data channel lightning protection	Yes	
Base Unit Cost*	$1410	
Data Memory	16K	
Stored Data Nonvolatile	No	
Program storage	EPROM	
Type of Communication (Radio, phone)	Modem	
Modem included	Yes	
Hayes Compatible	Yes	
Modem rate	1200	
Error checking Protocol	-	
Data transmission	-	
Auto call	Yes	
Relay control for Instant-off potential	Yes	Solid state triggered by remote
Case	-	
Software base	DOS	ASCII delimited text
Software flexibility	No	
OLE 2.0 Compliance	No	
ODBE Compliance	No	
Graphical Data Analysis	No	
Installation/Removal (wiring)	Specify	
Special Installation (mounting)	None	
Temp. rating	(-40 to 70) °C	
Humidity rating	0 to 95 %	
UL listing	No	
Warranty	1 Year	

The major features that the two units had in common included lightning/surge protection on all inputs and outputs, CP equipment independence, call-up addressability, battery backup, and relay control for IOP measurement.

---

* Includes the RMU and relay (for current interruption) assembled in a weatherproof enclosure.

There were a few significant differences:

1. The Metretek CPM II had differential-type channels while the JA Electronics PAC3 had common-ground-type channels. Differential channels are an advantage when two or more electrically isolated structures are to be monitored with the same RMU because each channel has an isolated positive and negative terminal. In a common ground unit, all channels share a common negative terminal.

2. The CPM II requires a proprietary "smart" modem for communication (available only through Metretek) while the PAC3 requires a standard Hayes-compatible modem (available from most computer hardware sales companies). Also, the proprietary modem is more costly at $1240 compared to the Hayes-compatible modem at $120.

3. The CPM II had Windows-based software, which is easier to use and configure than the DOS-based software provided with the PAC3 (although beta version of PAC3 Windows software was tested at Fort Drum). However, the PAC3 DOS-based software was inexpensive (i.e., free of charge with the JA Electronics units).

4. When taking IOP readings, the CPM II interrupts the current on the output (DC) side of the rectifier while the PAC3 interrupts the current on the input (AC) side. As a result of its design scheme, the PAC3 may present a greater shock hazard because the primary voltage is in the RMU cabinet — something that many technicians may not expect. Therefore, it may be prudent for the installation to provide specific safety guidance or additional RMU labeling for technicians working on PAC3 units. Apart from this issue, no decisive technical advantage to one approach over the other was observed.

5. The PAC3 is custom-fabricated and preconfigured at the factory for the rectifier it is intended to monitor. The CPM II is configured by the user through on-site programming of the electronically erasable and programmable read-only memory (EEPROM). The advantage of preconfiguration at the factory is that the user does not need to do any configuration; basically the RMU needs only to be connected and powered up. The disadvantage is that a preconfigured RMU may not be usable for a different application without factory reprogramming. For example, if the user wanted to use an existing RMU to monitor a new rectifier with a different maximum rated voltage output, the unit would have to be shipped back to the factory and reprogrammed. Units configured on-site (using EEPROMs) are more complicated to install because the user must program them, but this ultimately gives the user more control to accommodate site-specific changes in the CP system.

6. The PAC3 requires that the rectifier output current be measured via the voltage drop in a shunt placed in the negative return of the rectifier while the CPM II has no such requirement. There appears to be no advantage or disadvantage to either measurement approach.

7. The CPM II is a multiple-component system. Near the rectifier, two separately enclosed devices are required (the RMU and the power interrupter). At the host computer, a special modem and cabinet are required. The PAC3 is contained in one enclosure and uses a standard modem. Again, the PAC3 has the advantage of simplicity while the CPMII provides more flexibility in setup and application.

The Metretek CPM II components are pictured in Figures 1 through 4. The JA Electronics PAC3 unit is shown in Figures 5 and 6.

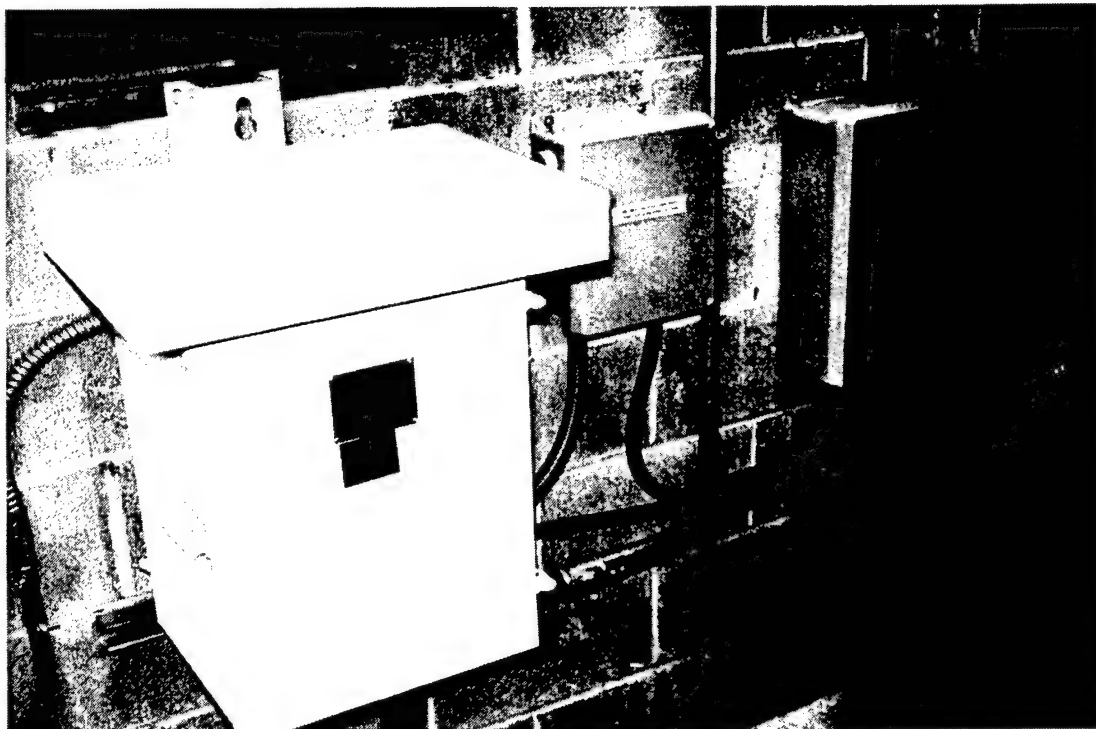**Figure 1. Metretek CPM II modular "smart" modem.**

Figure 2. Metretek RMU and Power Interrupter Module mounted near rectifier at Fort Drum.
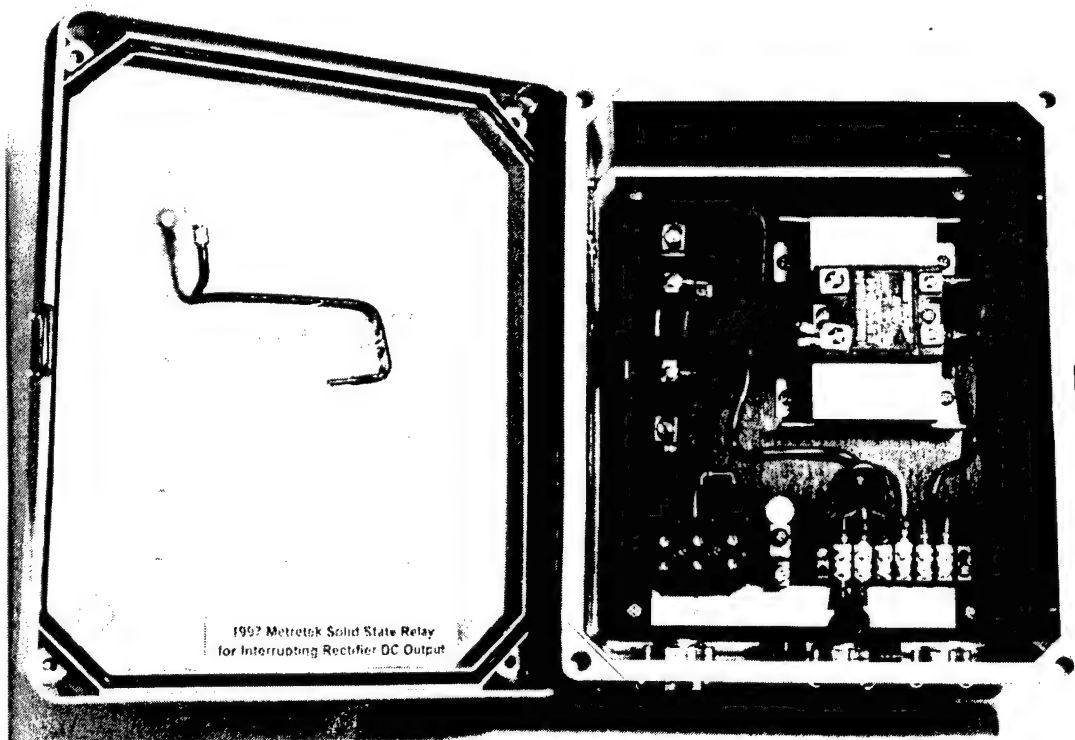

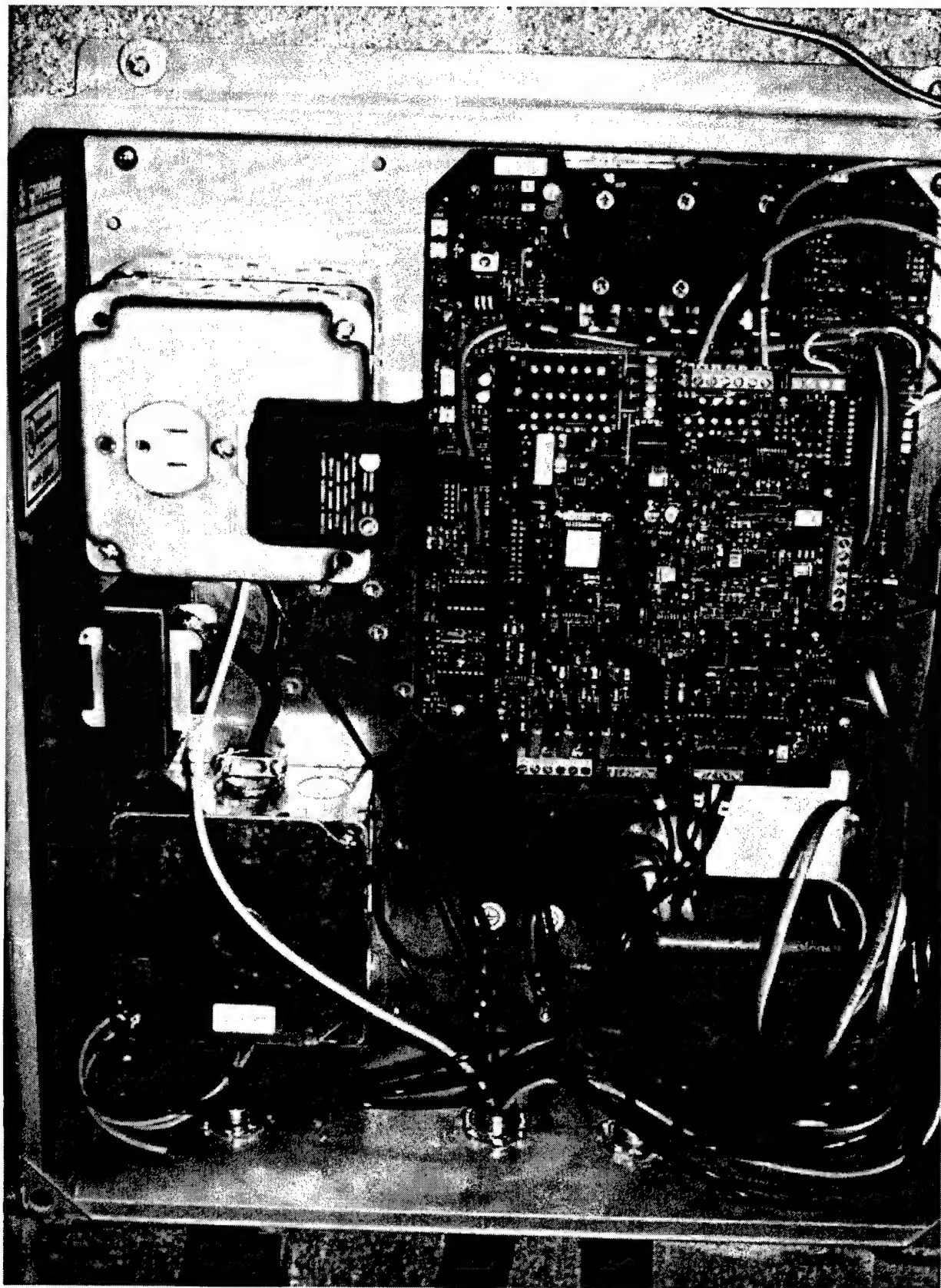Figure 3. Metretek power interrupter module.

Figure 4. Metretek CPM II remote monitoring unit.
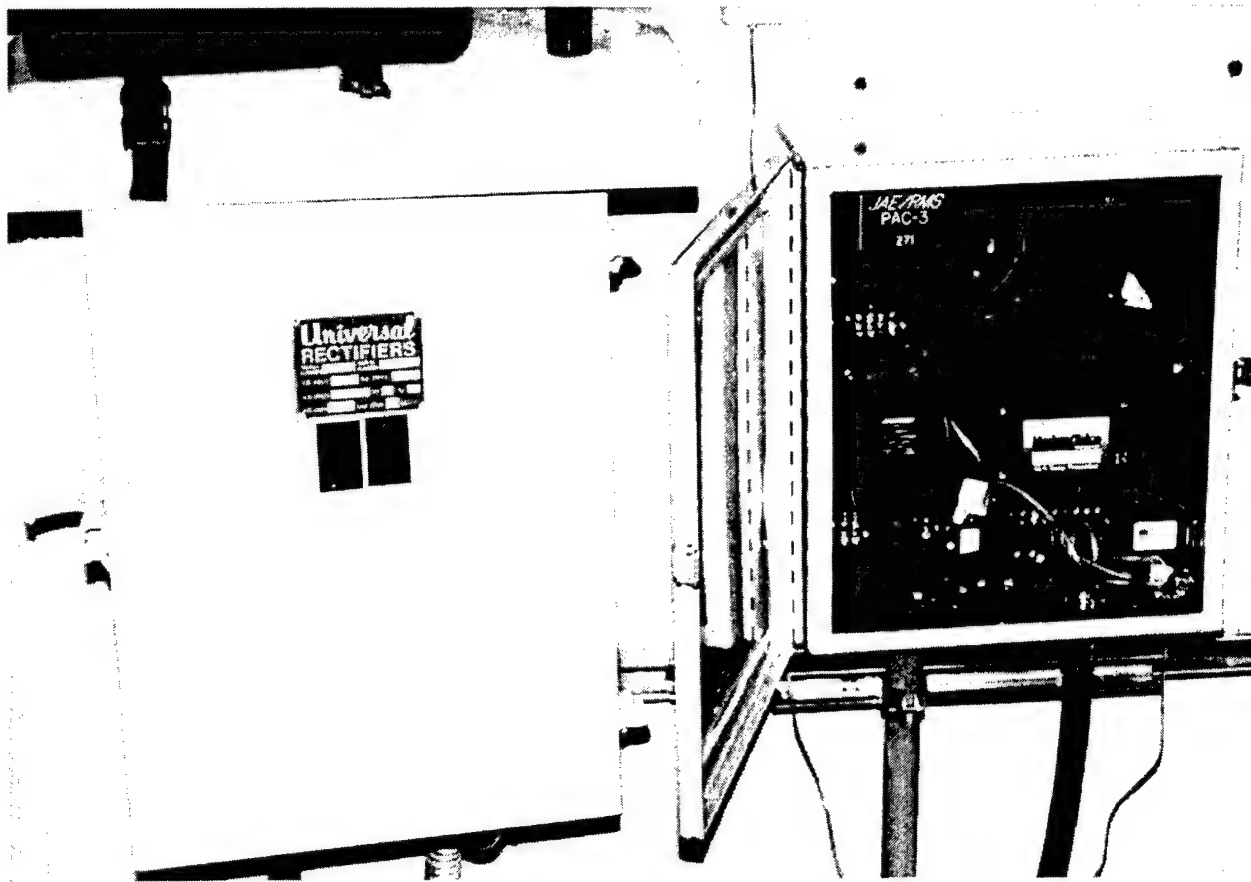
Figure 5. JA Electronics PAC3 unit installed next to rectifier at Fort Drum.
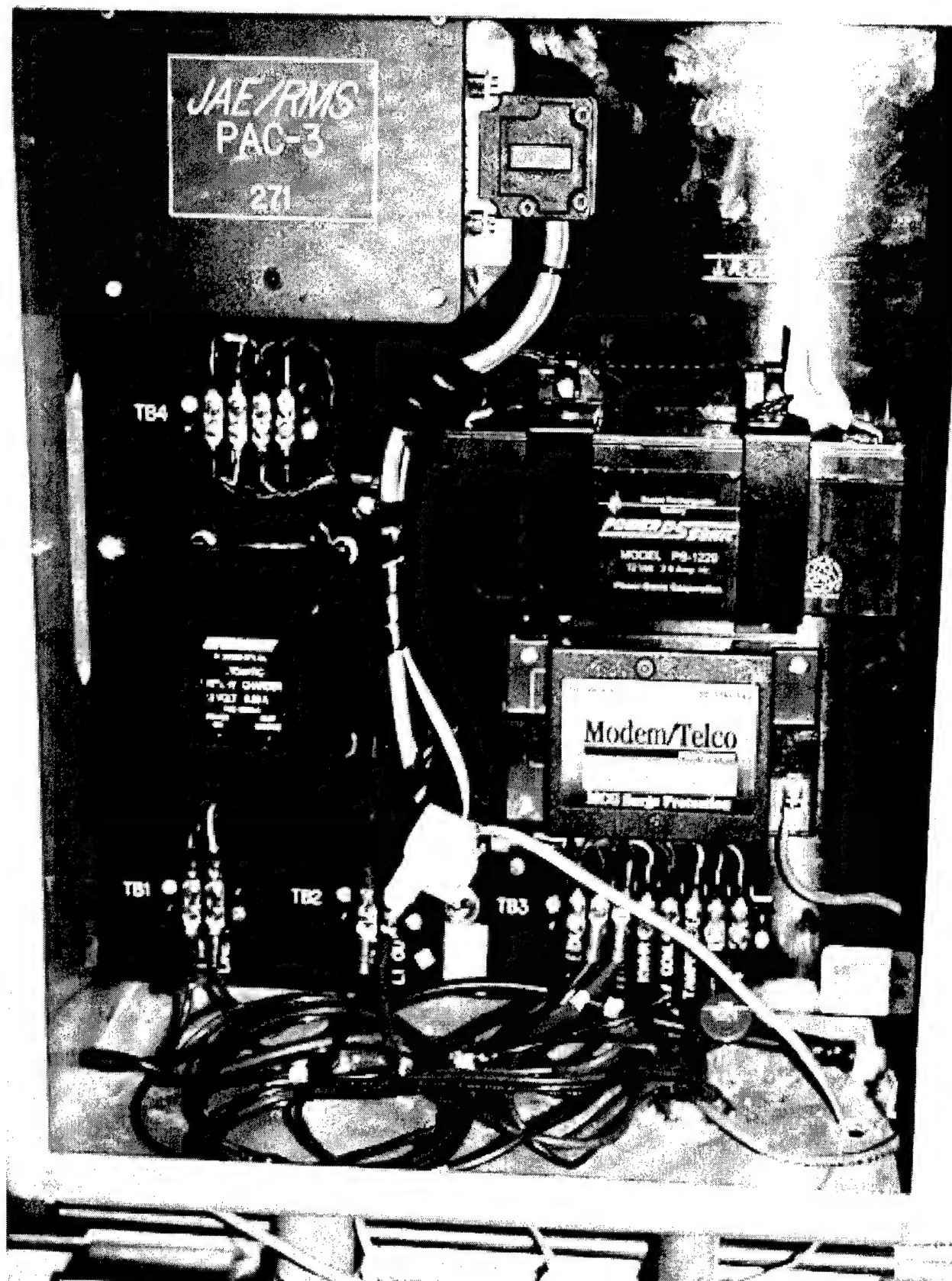
Figure 6. JA Electronics PAC3 remote monitoring unit.

3 RMU Evaluation Procedure and Results

During Phase I, an eight-step procedure was developed for evaluation of the RMU systems (Van Blaricum et al. 1997). The same procedure was used in Phase II. The evaluation focused on factors such as field installation, hardware performance and reliability, software performance, and quality of hardware and software manuals. The steps are described in order, and the results are documented for the Metretek CPM II and the JA Electronics PAC3. The MC Miller DAX units that were fully evaluated in Phase I are still in place at Fort Drum, and any new information about them is presented in the appropriate section.

Step 1: Evaluation of Hardware Manuals

The hardware manuals were reviewed and evaluated in terms of their clarity, completeness, and conciseness in documenting the preparation and procedures necessary for installing the RMU hardware. A good manual should be well organized and easy to follow. System components and their purposes should be clearly explained, and tools and equipment required to install the systems should be identified. Installation sequencing should be ordered, complete, and understandable, and any required post-installation field-testing should be explained.

Results: Metretek CPM II

Three hardware manuals were provided with the CPM II System: one for the modular S-Modem, one for the CPM II unit, and one for the Power Interrupter. Each manual was complete and very descriptive, and the step-by-step procedures were relatively easy to follow. The CPM II and Power Interrupter manuals should be studied thoroughly before configuring the CPM II system software. One minor problem is that there was no wiring schematic provided.   The electricians at Fort Drum had some difficulty installing the unit because of this.

Results: JA Electronics PAC3

One manual was provided with the PAC3, but it is dedicated mainly to the software. The only information given about the hardware was a one-page wiring

schematic. Although the system hardware is very well labeled, most users will require more information to perform a complete and proper installation. The electricians at Fort Drum found the schematic helpful during the installation, but there were two items that required further clarification from the manufacturer. First, it was unclear that the current shunt was required to be on the negative output of the rectifier. Second, the documentation was unclear regarding the location of the circuit interruption. All other units tested interrupt the DC output of the rectifier, but the PAC3 interrupts the AC power input.

Step 2: Evaluation of Hardware Installation Procedures

One RMU from each manufacturer was installed at the outdoor USACERL CP test site in Champaign, IL. All tests were performed on a 3 in. diameter bare steel pipe 40 ft long.* Telephone lines were routed to the RMUs from a nearby building.

At Fort Drum, the RMUs were demonstrated on the impressed current CP system that protects the underground high-temperature hot water (HTHW) distribution system. One RMU from each manufacturer was installed at Fort Drum. The Metretek CPM unit was installed in the mechanical room of the chapel on Po Valley Road (Building 4405). The JA Electronics PAC3 unit was installed in the mechanical room of a barracks (Building 10612).

Permanent copper-copper sulfate reference cells were buried at all test locations approximately 12 to 24 in. from the pipe at pipeline depth. Additional details on the test sites can be found in the Phase I report (Van Blaricum et al. 1997).

RMUs were evaluated for ease of installation at both sites. Installation and initial testing problems were documented. The manufacturer support required during this process was noted and appraised as to speed, clarity, and effectiveness of response.

---

* 1 in. = 2.54 cm; 1 ft = 0.3048 m.

Results: Metretek CPM II

The CPM II was somewhat complicated to install and service. Most first-time users will probably find the installation procedure to be confusing because of the numerous steps involved. However, after the user has completed a CPM II installation the procedure should be easier to understand, and future installations should be simpler. Approximately 15 jumpers must be correctly positioned in the RMU to select the correct configuration for each unit. The local level of technical expertise and level of technical support available from the manufacturer will be critical in assuring that these jumpers are set correctly. In fact, even though the staff at Fort Drum was exceptionally well qualified, the jumpers were initially set incorrectly because of a nonuniform labeling scheme used on the printed circuit board associated with these jumpers. Technical support provided by Metretek was adequate and helpful in configuring the units, but it was sometimes difficult to get an immediate response from the company. It was not uncommon for a delay of 1 or 2 days before a user call for assistance was answered by the company.

Special attention should be given in advance to which RMU inputs should be used because there are several options for configuring both rectifier and pipe-to-soil monitoring and power interruption connections. These options pertain to the impedance and range of the voltages to be measured and the range multipliers to be used in calculating current flow.

Results: JA Electronics PAC3

The PAC3 was the easiest of all units tested to install and service. There was no procedure in the manual for setting up the unit, but labeled terminal strips provided in the unit itself and the schematic in the manual made installation easy. However, a novice RMU user probably would need additional explanation on the installation procedure. Technical support was readily available from the manufacturer for questions and problems that occurred during installation.

Special attention should be given in advance to the current-measuring shunt in the rectifier to be monitored by the PAC3. The PAC3 normally requires a shunt at the negative side of the rectifier output circuit, but some rectifiers are designed with the shunt at the positive side of the output circuit. If the rectifier does have a positive-side shunt, the user must specify this to the manufacturer when the RMU is ordered so the PAC3 can be built to accommodate this rectifier circuit design. Also, as noted, the PAC3 relay breaks the rectifier AC power input instead of the rectifier DC output. This could present some greater shock

hazard in the cabinet because the primary voltage (which could be as high as 480 VAC) is in the RMU cabinet—something many technicians may not expect.

Results: MC Miller DAX

One of the problems with the DAX units evaluated in Phase I was that the mounting hardware made it difficult to install and replace them. The DAX units have been redesigned to make installation, wiring, and replacement easy. The "plug-in" wiring connection blocks provided at both ends of the DAX RMU are now mounted using knurled thumb screws. The same types of thumb screws are used to hold the DAX module to the cabinet mounting panel. Fort Drum personnel estimated that removing or replacing the redesigned DAX would now take less than 5 minutes, as compared to 30 – 60 minutes for the original DAX design. Similarly, the complete RMU system — including the DAX, current interrupter components, back-up battery, power supply, and battery charging system — are all mounted on a single panel held in place within the cabinet by four wing nuts. The entire system may easily be removed from the enclosure and replaced by removing the four wing nuts and disconnecting the power and monitoring point lead wires.

Step 3: Evaluation of Software Manuals

The software manuals were reviewed in terms of their adequacy for both novice and experienced RMU users. The instructions were evaluated for clarity, completeness, and conciseness. A good manual should clearly present the procedures necessary to install the software on the master computer. System requirements should be clearly identified. Procedures for using the software, setting the necessary operating parameters, obtaining data, exporting data to a spreadsheet, and enabling automated monitoring features should be explained clearly and in detail.

Results: Metretek CPM II

The software manuals for the CPM II system were lengthy but thorough. The configuration of the software is very complex but can be done by carefully following the instructions in the manuals. The CPM II system has two sets of software, with separate manuals for each set. One manual is for the cathodic protection monitoring and control (CPM) software; the other is for the unit's EEPROM software which is used to program the EEPROM in the monitoring and control module (MCM). The latter software is required, among other things, for

naming the CPM II RMU and implementing the autodial feature for alarm reporting.

The CPM software manual for the CPM II system is considered excellent in terms of its content. It provides clear, detailed, step-by-step instructions for properly setting up the software for use with the RMU. As a result of this detail and the software's versatility and power, the manual is lengthy and requires many hours to read thoroughly. It provides good illustrations of most input screens and gives some examples to assist in selecting various software settings. However, it may leave the novice user unsure of some selections. More emphasis on manufacturer's preferences and/or default settings would be helpful.

Overall, there are six manuals provided with the Metretek system. It would be far less tedious to install and configure CPM II if the manuals could be consolidated into a single loose-leaf binder and the user could be provided with some general guidance on the setup process. A "quick start" section for configuring the software would also be helpful.

A "Read Me" file appears at the end of the CPM software installation to inform the user of several database initialization options and Windows date and time format changes that must be made before launching the CPM program. It would have been helpful if a printed copy of the information in the Read Me file was included in the manual.

The software manuals were considered adequate for both novice and experienced RMU users. Even the experienced user who typically requires very little assistance in configuring software would need to read the manual thoroughly, due to the large number of options and their functional definitions.

Results: JA Electronics PAC3

The software manual for the PAC3 System is considered adequate, but difficult for novice RMU users to follow. It provides reasonably good explanations of each configuration option, but lacks illustrations and examples. The manual is relatively lengthy due to the large number of configuration options. A more detailed Table of Contents would be helpful. The manual is considered adequate for experienced RMU users who would be more familiar with monitoring system configurations and demands.

Step 4: Evaluation of Software Installation, Configuration, and Technical Support

Installation and configuration procedures were evaluated according to software loading time required, ease of configuring the software to perform the desired measurements, and the amount of technical support required. Configuration or compatibility problems and issues were recorded along with the appropriate solution.

Results: Metretek CPM II

Software loading. The CPM II software is contained on seven diskettes. It took approximately 20 minutes to fully load, which was considerably longer than the loading time for other units. The package included the database software, as well as ReportSmith, which produces reports and graphs with the data from the remote unit. The EEPROM software is contained on one diskette and takes only about 1 minute to load. NOTE: The user should review a copy of the *Cathodic Protection Monitoring Software Installation* manual and *Cathodic Protection Monitoring System Version 2.40 User's Guide* before attempting to load software, otherwise some of the screens displayed during installation may not appear to be self-explanatory.

Software configuration. The majority of the CPM software was relatively easy for an experienced user to configure when the manual was followed closely. However, novice users would be expected to have some difficulties.   A full configuration for one CPM II unit should take less than 15 minutes after the user has become familiar with the software and hardware.

One problem was that the manual did not contain adequate information for configuring the relays used to interrupt the DC output of the rectifier. The information for the relays was found in the Power Interrupter Manual. Another problem that surfaced during software configuration was the incompatibility of the unit's proprietary modem with one of the computers used in the demonstration. The modem problem is discussed in detail under "Hardware Evaluation."

The version of EEPROM software used in this evaluation required a direct connection between the COM1 port of the programming computer and the CPM

II unit using a special cable that was supplied with the RMU. Consequently, this step in the configuration procedure requires someone to go to the RMU in the field with a portable computer and program information into it. (A new version of the EEPROM software that permits remote programming is reportedly available, but it was not evaluated in this demonstration.)

It was relatively easy to configure the EEPROM software and program the RMU. The EEPROM software could not be made to work with a Toshiba Tecra 720 portable computer, but the problem was overcome by using a Dell laptop computer.

Technical support. There was no phone number given in the manual for technical assistance, but the vendor's order line provided a name and toll-free number for technical questions. It was sometimes difficult to get immediate assistance, but calls were generally returned within a day or two.

Results: JA Electronics PAC3

Software loading. PAC3 software is contained on only one diskette. The DOS version was loaded and operated under Microsoft Windows in about 1 minute. Installation was straightforward except that the unit could not access the Toshiba Tecra 720 CDT modem. It did work on both a desktop computer using an AMD K-6 233 MHz processor and an internal U.S. Robotics modem as well with a Dell laptop computer. When the software was first loaded on a desktop computer at Fort Drum, using a genuine Hayes modem (as requested by JA Electronics technical support personnel), the software would not work. An external U.S. Robotics Sportster 33.6 modem (similar to the desktop modem) was then substituted for the Hayes unit, and communication was immediately successful.

Additionally, a beta release of a Windows version of the PAC3 software was partially evaluated during the demonstration. It loaded as easily as the DOS version and operated correctly regardless of which computer it was loaded on. A commercial version of this software was expected to be released by the time this user guide is published.

Software configuration. The DOS version of the software was relatively easy to configure. Although it does not support the Windows graphical user interface, the menus and commands are simple and logical; users were able to take readings minutes after the software was loaded. However, some difficulty was encountered in establishing scale factors and the user had to call the vendor for

technical support. A full configuration of one PAC3 unit should take less than 15 minutes after the user has become familiar with the software.

One inconvenience is that the PAC3 RMU must be actively connected for the user to view and configure the software; other RMU software may be run without a live connection to the RMU.

Technical support. Technical assistance was readily available from JA Electronics. The vendor provided a name and number for technical questions. This was not a toll-free number, but very helpful and knowledgeable technical support was provided free of charge by JA Electronics staff. The level of support was considered very good for experienced and novice RMU users.

Results: MC Miller DAX

The Daxit software allows the user to completely reconfigure RMUs from the master computer. This includes definition of the ranges and offsets for each and every channel, types of measurements taken on each, alarm levels (both upper and lower limits), unit ID number, etc. In addition, the unit's EEPROM can be completely reconfigured when the operating software for the RMU is updated or upgraded. This means that the user does not need to travel to the RMU to perform any of these operations.

Step 5: Evaluation of Software Use

Software was evaluated throughout the RMU demonstration period and addressed the following issues:

- Ease of operation (user-friendliness).
- Software versatility. A good software package should be easily adaptable to a variety of situations and configurations. Versatility addresses such issues as whether the software can interrogate both single units and multiple units or whether the software allows remote configuration of the RMU.
- Software interface appearance.
- Help function. This refers to the usefulness and completeness of the on-line help feature.
- Data report format. This refers to the clarity, flexibility, and appearance of the standard data reports produced by the RMU software.
- Exportability. This refers to the ability of the software to organize and format data for use by other programs such as spreadsheets.

- Alarm capability. This refers to an automatic alarm to notify the operator if a problem has occurred with the CP system.
- Synchronized interruption. This refers to the ability of the software to perform interruption of several rectifiers simultaneously.
- Availability of a software uninstall feature.

Results: Metretek CPM II

Software versatility. The CPM II software versatility was considered excellent. When configuration is complete, the software is easy to use and comes with report and graph generating software. The software allows for easy monitoring of either single or multiple units, real-time alarm reporting, and rectifier on/off synchronization. Multiple units can also be treated as a group. Two-way communication for control and monitoring purposes is supported and alarm reporting is supported.

Help function. The help function provided with the software was considered excellent. The style was similar to the on-screen help typical of most Windows-based software, and the level of detail was similar to the manual. The function is easy to use and allows the user to click on highlighted words in the help file for more information on that topic. A help icon is also available in the Metretek program group. This can be more convenient than using the printed manual. The help function would be very useful for experienced or novice RMU users.

Ease of operation. As discussed before, the CPM II software is somewhat difficult to set up, but when setup is complete, it has an attractive, well organized Windows-based interface. The software is relatively user-friendly once the user is accustomed to working with multiple modules at the same time. Each module is attractively presented and well organized, having the same feel as most other well designed Windows applications. Both novice users (with some training) and experienced users should find the software easy to operate. The ease of operation was rated as very good.

Data format. The standard data reports provided by the CPM II software were clear and easy to read. The Metretek system uses a report-generating software package called ReportSmith, which utilizes the Paradox database engine. ReportSmith produces attractive reports and graphs of data gathered by the unit. Reports can be generated for combinations of units and combinations of monitored/controlled parameters, and data can be viewed in a tabular or graphical format. A variety of user-selectable report formats is provided, including bar

graphs, line graphs, area graphs, and pie charts. Full editing capability is provided for graphical formats. The data can also be exported into a spreadsheet program such as Microsoft Excel or Lotus 1-2-3.

Alarm capability. The CPM software supports the setting of alarm conditions to notify the operator that a problem has occurred in the CP system. However, the alarm capabilities were not tested in this project. Another feature of the programmable alarms is the ability to set the number of repeat occurrences of an out-of-limit event before triggering the alarm. Additional alarms are incorporated into the RMU system. These include AC power, tamper switch, communications errors, clock synchronization, and several others. Alarm logging and reporting are flexible; alarm events can be reported immediately, during a scheduled call in from the RMU, or during a poll from the host computer.

Synchronized interruption. The Metretek system has the ability to perform synchronized interruption. Normally, when synchronizing the interruption of two or more rectifiers, the time at each rectifier is referenced to the master computer. This method is not very accurate and therefore it is difficult to interrupt the rectifiers at precisely the same moment. The Metretek system has a proprietary "smart" modem that maintains a much more accurate time. The CPM software supports synchronization of the clocks of multiple units. This in turn permits synchronized interruption of multiple rectifiers through CPM software control. Synchronized interruption is a very important feature that will allow accurate measurements of cathodic protection IOPs on piping systems protected by multiple rectifiers. A test of this feature was not included during this evaluation because only one CPM II unit was installed.

According to Metretek, the proprietary modem is necessary for their system to provide synchronized interruption. Based on this requirement, the desktop PC must regularly communicate with each RMU being simultaneously interrupted. This approach could result in long distance telephone charges if the master computer is not within the same local access area.

Uninstall feature. The CPM software does not have an uninstall feature. Removal of the software, unless it is installed in conjunction with a quality uninstall program, may be difficult or even impossible. If conflicts appear between the host computer and the CPM software, the lack of an uninstall feature could make the problem difficult to eliminate without formatting the entire hard drive and re-installing all software.

Results: JA Electronics PAC3

Software versatility. The PAC3 software was considered very versatile. Both two-way communication for control and monitoring purposes and for alarm reporting are supported. The RMU clock has a remotely programmable speed adjustment as well as a remote reset feature. The software also allows for easy monitoring of either single or multiple units.

Help function. There was no on-line help function provided with this software. However, the manual provided with the system would be adequate for troubleshooting typical software problems.

Ease of operation. The DOS-based PAC3 software is very easy to use because it comes pre-configured and the user interface is user-friendly. Although it does not have the look and feel of Windows-based software, the menu-driven interface is simple and logical. Both novice and experienced users will find this software acceptable and easy to operate.

Data format. The standard data reports provided by the PAC3 software were clear and easy to read. The data can be logged to a file or output directly to a printer. The data format was rated as very good.

Alarm capability. The PAC3 software supports remote programmable range limit alarms for each input channel. System status alarms (tamper switch, AC power, communications errors, etc.) are incorporated into the RMU system.

Synchronized interruption. The PAC3 software can perform synchronized interruption of multiple rectifier units, but this requires that an additional card be installed in the RMU. The card was not purchased or tested in this demonstration. This could be a problem for a user who has multiple rectifiers installed on a single piping network and requires synchronized interruption, but does not realize that a PC card must be ordered at extra cost to have this capability. Synchronized interruption of multiple rectifiers is very often required for accurate cathodic protection system evaluations.

Uninstall feature. The built-in uninstall feature in the software package was powerful and useful, both for the novice and experienced computer operator. The function quickly and automatically removes the PAC3 program, its subdirectories, and all associated system files and settings. The software could easily be reinstalled and upgraded with no problem. The only problem with the

uninstall feature is that it is not installed on the computer when the program is installed. It must be executed from the source disk.

Results: MC Miller DAX

The Daxit software is fully compatible with Window 3.1, Windows 95, and Window NT. It has been upgraded since the Phase I demonstration to provide more flexibility. The single module interrogation and analysis software package and compliance with Windows operating conventions make the software both intuitive and easy to use.

The single biggest improvement to the Daxit software was the reported implementation of synchronized interruption capability using any one of the rectifier RMUs as the master synchronizing unit. The master unit, via modem, regularly contacts each of the other units to be interrupted, and simultaneously keeps up to 50 units synchronized to interrupt within 30 milliseconds of each other. This capability could not be tested in the FEAP demonstration because there were not enough units installed at any of the test locations.

Step 6: Evaluation of Hardware Features

RMU hardware abilities and reliability were rated. A log of all problems encountered throughout the evaluation was maintained. The manufacturer support required during this process was noted and appraised as to speed, clarity, and effectiveness of response. Other factors and features considered included safety, surge protection, reliability of the relay that interrupts the CP current, and ability to program the RMU remotely from the master computer.

Results: Metretek CPM II

The first Metretek CPM II unit shipped to USACERL did not include the relay to interrupt the current for IOP readings. A relay already installed at USACERL was connected, but it would not work because the CPM II requires a special proprietary relay. A proprietary relay was obtained for the Fort Drum site and it performed well.

The telephone line surge protection did not come prewired from the factory, and the telephone wire that ran from the surge protection box to the unit was missing from the original shipment. Metretek sent the phone wire at

USACERL's request. The surge protection was wired according to specifications and mounted next to the unit.

Difficulties occurred in setting up some master computers to work with the CPM II. As noted previously, it could not be set up to work with a Toshiba Tecra 720 CDT computer operating under Windows 95, Service Release 2.01. This difficulty was due to the proprietary modem furnished by Metretek. According to Metretek, the modem is necessary for the CPM II to provide synchronized interruption. The compatibility problem did not exist when the Metretek modem was used with an older model Dell portable computer during the field-tests at Fort Drum. This compatibility issue is not expected to be a problem with other computers as long as the Metretek modem is the only modem connected to the master computer. Some systems (such as the Dell portable) may not exhibit interrupt (IRQ) or other software/hardware conflicts when using multiple modems. This potential conflict should be investigated by the prospective user of the Metretek system before a commitment to purchase is made.

The CPM II cannot be reprogrammed remotely, but the user can reprogram it onsite by connecting a laptop computer directly to the unit. This arrangement is inconvenient, but it is preferable to totally replacing the read-only memory or shipping the EEPROM module back to the vendor for reprogramming.

Results: JA Electronics PAC3

The relay provided with the PAC3 was a steady state, normally open relay. This is undesirable because if power to the monitoring system is lost, the relay is left open and cathodic protection of the structure is lost. It is better to have a mechanical, normally closed relay that maintains cathodic protection on the structure even if power to the monitoring unit is cut off. The problem was corrected by using the relay provided with the unit to control the normally closed mechanical relay already installed at the USACERL test site.

The unit intended for Fort Drum had another problem with the relay. The relay provided with the unit was rated for much higher voltages than would be used in any cathodic protection system. The manufacturer recognized the mistake and sent the correct relay.

Throughout the evaluation the PAC3 unit was unable to make accurate current readings at the USACERL test site. It is believed that this problem was due to a miscommunication between USACERL and JA Electronics regarding the location of the current-measuring shunt in USACERL's rectifier. As noted previously, the

PAC3's standard configuration requires that the current be measured by a shunt located in the negative return of the rectifier. This was not the situation in USACERL's rectifier. This error underlines the importance of making sure that the exact configuration of the current-measuring shunt in the CP rectifier is known and that this information is clearly communicated to the vendor.

The PAC3 system is preconfigured at the factory. It can only be reconfigured by replacing the EEPROM module, as was done during the field-test at Fort Drum. This is much more difficult than reprogramming by direct computer hookup (as done with the Metretek unit) or by the even simpler process of reprogramming by remote computer link, as done with the MC Miller Unit. This aspect of system design is considered a major shortcoming as upgrades and improvements in the operating system cannot readily be implemented on the PAC3 System.

Step 7: Evaluation of Equipment Accuracy

At the USACERL test site, remote and manual on-site measurements were taken daily (Monday through Friday) to evaluate the accuracy of the RMUs. The manual on-site measurements were taken with a Fluke Model 87 True RMS Digital Multimeter (DMM), and the types of readings taken were the same as those in Phase I (Van Blaricum et al. 1997).

At the Fort Drum test site, the accuracy of the remote monitoring equipment was checked at the time of installation by comparing the RMU readings with readings taken on-site with a Fluke Graphical Multimeter.

Results: Metretek CPM II

The daily readings taken remotely with the Metretek CPM II at the USACERL test site are plotted in Figures 7, 8, and 9. The readings taken with hand-held meters are shown for comparison. There was a power failure at the test site between 5 June and 30 June so there are no data points shown on the graphs between those dates. The power failure occurred when a lawnmower severed the site's electrical supply cable. Furthermore, master computer malfunctioned in early July, so there are several days during that time when readings were not taken. (The computer malfunction was unrelated to the remote monitoring equipment.)

The rectifier output voltage measurements (Figure 7) varied slightly during the test period. All rectifier output voltage measurements taken by the CPM II

during the test period were more than 95 percent accurate, with an average accuracy of 98.47 percent.

The first half of the rectifier output current plot in Figure 8 shows that the CPM II readings were consistently about 400 mA lower than the manual readings. This was easily corrected by recalibrating the unit, as shown by the accurate readings recorded in the later half of the test period. All rectifier current readings taken after the recalibration were more than 87 percent accurate, with an average accuracy of 93.57 percent.

Figure 9 shows the daily pipe-to-soil "on" potentials. All "on" potential readings were more than 91 percent accurate, with an average accuracy of 95.90 percent.

IOPs were not tested at the USACERL test site because a proprietary current interrupter was required. Only one interrupter was procured and it was installed at the Fort Drum test site.

The Metretek CPM system installed at Building 4405 (Rectifier 12) at Fort Drum was demonstrated to be operational, and it recorded accurate data during the field evaluation (Table 3). Metretek's proprietary power interrupter module was installed at this location, and the field evaluation showed that the system is capable of interrupting the rectifier and accurately measuring the IOP.

Table 3. Results of Metretek CPM II test at Fort Drum Bldg. 4405 (Rectifier 12).

Measurement	CPM II Unit	Independent Meter	Pct Accuracy
Rectifier output voltage (V)	43.25	43.80	98.74
Rectifier output current (A)	10.80	10.62	98.31
Pipe-to-Soil "On" Potential (-V)	1.780	1.733	97.29
Pipe-to-Soil "Instant-Off" Potential (IOP) (-V)	1.580	1.571	99.43

Results: JA Electronics PAC3

Figure 10 shows the daily rectifier output voltage measured at the USACERL test site. The reason for the low voltage spike in the early part of the test period is not known. With the exception of the spike, all rectifier voltage readings taken by the PAC3 were more than 95 percent accurate, with an average accuracy of 98.61 percent.

As noted previously, the error in specifying the shunt location for the USACERL test site made it impossible to accurately measure rectifier output current. Therefore, readings are not reported here.

Figure 11 shows the daily pipe-to-soil "on" potentials and Figure 12 shows the IOPs. The fluctuations in the potential readings are probably due to the shunt problem also. The results from the Fort Drum test site showed that these problems can be readily corrected by reinstalling the shunt in the negative circuit of the rectifier (see below).

The PAC3 unit was installed at Building 10612 (barracks), Rectifier 19. The field evaluation showed that the system was operational, but the rectifier was not compatible with the RMU (primarily due to the location of the shunt). The rectifier current measurement differed by 5 percent from the value measured with a portable meter. The pipe-to-soil potential measurement differed by 54 percent. Because of the shunt location problem, the rectifier voltage measurement was assumed not to represent the true value.

The problem was corrected by reinstalling the shunt in the negative circuit, and the unit is now reading accurately, as shown in Table 4. This evaluation demonstrated the PAC3's ability to interrupt the rectifier and measure an "instant-off" pipe-to-soil potential.

Table 4. Results of JA Electronics PAC3 test at Fort Drum Bldg. 10612—Rectifier 19 (after re-installation of shunt in negative leg of rectifier).

Measurement	PAC3 Unit	Independent Meter	Pct Accuracy
Rectifier output voltage (V)	55.50	56.40	98.40
Rectifier output current (A)	5.62	6.09	92.28
Pipe-to-Soil "On" Potential (-V)	1.667	1.715	97.20
Pipe-to-Soil "Instant-Off" Potential (IOP) (-V)	1.160	1.176	98.64

Results: MC Miller DAX

As noted previously, the MC Miller DAX units from Phase I are still in place at Fort Drum. These units were tested again during the Phase II site visit. Results are given in Tables 5-7. They show that the units are continuing to provide highly accurate measurements of all parameters.

Table 5. Results of MC Miller DAX test at Fort Drum Bldg. 11050 (Rectifier 49).

Measurement	DAX Unit	Independent Meter	Pct Accuracy
Rectifier output voltage (V)	58.80	58.90	99.83
Rectifier output current (A)	3.33	3.30	99.09
Pipe-to-Soil "On" Potential (-V)	1.180	1.182	99.83
Pipe-to-Soil "Instant Off" Potential (IOP) (-V)	0.984	0.984	100.00

Table 6. Results of MC Miller DAX test at Fort Drum Bldg. 11030 (Rectifier 41, Circuit A).

Measurement	DAX Unit	Independent Meter	Pct Accuracy
Rectifier output voltage (V)	57.70	57.90	99.65
Rectifier output current (A)	2.88	3.00	96.00
Pipe-to-Soil "On" Potential (-V)	0.870	0.880	98.86
Pipe-to-Soil "Instant Off" Potential (IOP) (-V)	0.704	0.713	98.74

Table 7. Results of MC Miller DAX test at Fort Drum Bldg. 11030 (Rectifier 41, Circuit B).

Measurement	DAX Unit	Independent Meter	Pct Accuracy
Rectifier output voltage (V)	57.00	57.20	99.65
Rectifier output current (A)	5.61	5.61	100.00
Pipe-to-Soil "On" Potential (-V)	0.874	0.880	99.32
Pipe-to-Soil "Instant Off" Potential (IOP) (-V)	0.704	0.713	98.74

Step 8: Analysis of Results and Ranking of RMUs

The matrix approach that was developed in Phase I to rank the RMUs according to the evaluated features (Van Blaricum et al. 1997) was also used in Phase II. A hardware matrix and a software matrix were developed. Each feature was assigned a weighted factor on a scale of 1 to 10 based on its importance, with the most important features receiving a factor of 10. Each RMU system was graded to each feature on a scale of 1 to 5, where 5 was considered excellent, 4 was considered very good, 3 was average, 2 was acceptable, and 1 was unacceptable. To score for each feature, the weighting factor was multiplied by the grade. The scores for each RMU were then subtotaled to obtain a hardware score and a software score. The hardware and software scores were added to obtain an overall RMU system score. The highest and lowest possible system scores for hardware or software were 250 and 50, respectively. The highest and lowest possible overall system scores were 500 and 100, respectively.

The hardware and software matrices used to rank the RMUs are shown in Tables 8 and 9. The MC Miller DAX scored highest with an overall score of 464. The Metretek CPM II was next with a score of 390. The JA Electronics PAC3 received a score of 291.

Table 8. RMU software comparison matrix.

Feature	Factor	CPM II (Metretek)		PAC3 (JA Electronics)		DAX (MC Miller)	
		Rating	Score	Rating	Score	Rating	Score
Software manual	1	4	4	3	3	4	4
Software manual (novices)	1	4	4	2	2	4	4
Software manual (experts)	1	4	4	3	3	4	4
Technical support (software)	5	2	10	5	25	5	25
Toll free number	1	1	1	1	1	5	5
Software operation	5	3	15	3	15	5	25
Software loading	1	4	4	5	5	5	5
Software configuration	2	3	6	3	6	5	10
Software versatility	5	5	25	4	20	5	25
Software appearance	2	5	10	2	4	5	10
Help function	2	4	8	1	2	4	8
Ease of operation (single unit)	2	5	10	3	6	5	10
Ease of operation (multiple units)	4	5	20	3	12	5	20
Data report format	3	5	15	3	9	5	15
Exportability to MS Excel	2	5	10	1	2	5	10
Spreadsheet formatting	2	5	10	1	2	5	10
Alarm capability	5	5	25	5	25	5	15
Synchronized interruption	5	5	25	3	15	5	25
Uninstall feature	1	1	1	5	5	5	5
Software Score			**207**		**162**		**235**

Table 9. RMU hardware comparison matrix.

| Feature	Factor	CPM II (Metretek)		PAC3 (JA Electronics)		DAX (MC Miller)	
		Rating	Score	Rating	Score	Rating	Score
Hardware manual	2	4	8	1	2	3	6
Ease of installation	3	3	9	2	6	5	15
Safety (high voltage exposed?)	5	5	25	1	5	5	25
Safety warning labels	3	1	3	1	3	1	3
Technical support (hardware)	5	3	15	5	25	5	25
Interrupter relay	5	4	20	2	10	4	20
Data accuracy	10	5	50	3	30	5	50
Reliability	10	4	40	4	40	5	50
Surge/lightning protection	5	3	15	3	15	5	25
Remote programming	2	3	6	1	2	5	10
Hardware Score			183		138		229
Software Score (Table 8)			207		153		235
OVERALL SCORE			390		291		464
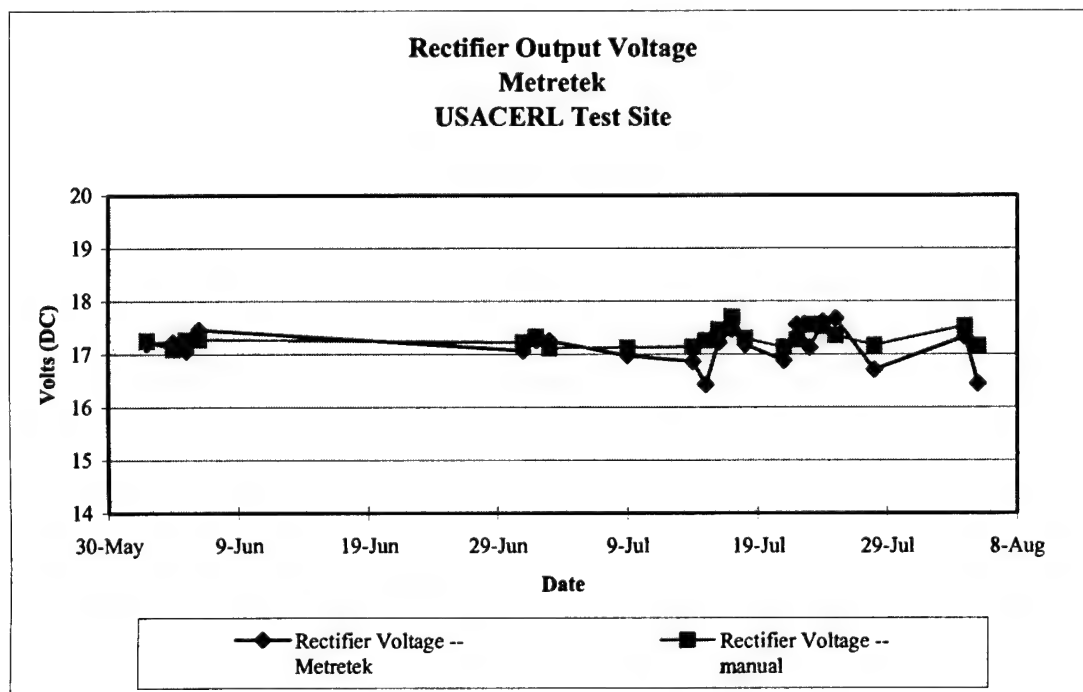
Figure 7. Rectifier output voltage measured by Metretek CPM II at USACERL test site.
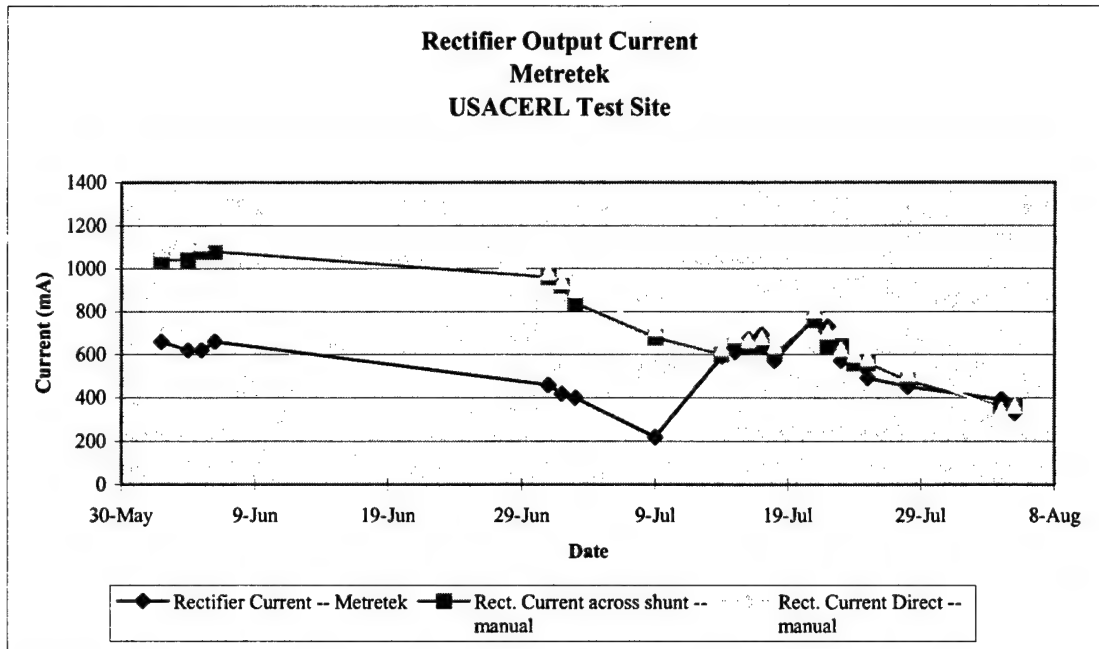
Figure 8. Rectifier output current measured by Metretek CPM II at USACERL test site.
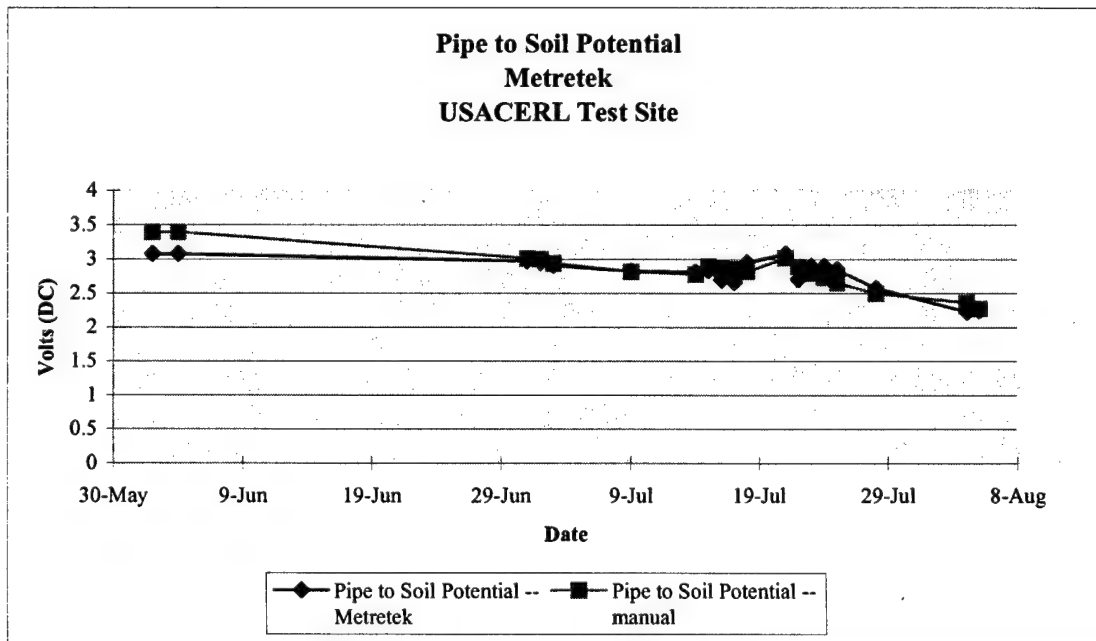

Figure 9. Pipe-to-soil "on" potential measured by Metretek at USACERL test site.
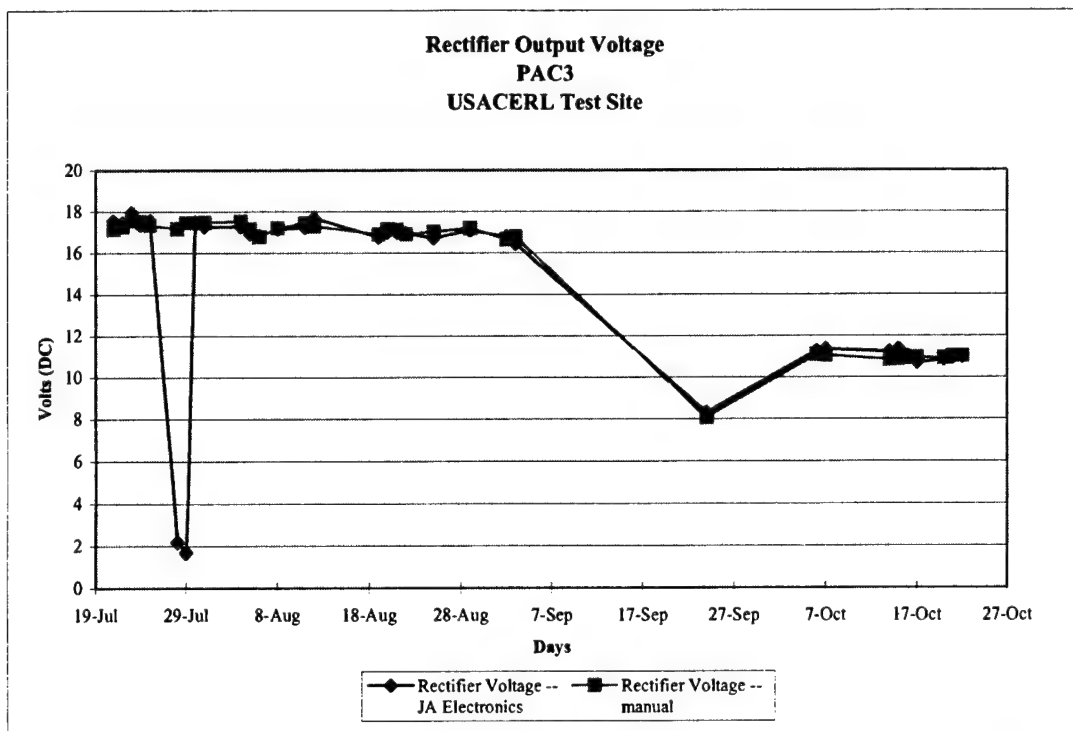
Figure 10. Rectifier output voltage measured by JA Electronics PAC3 at USACERL test site.
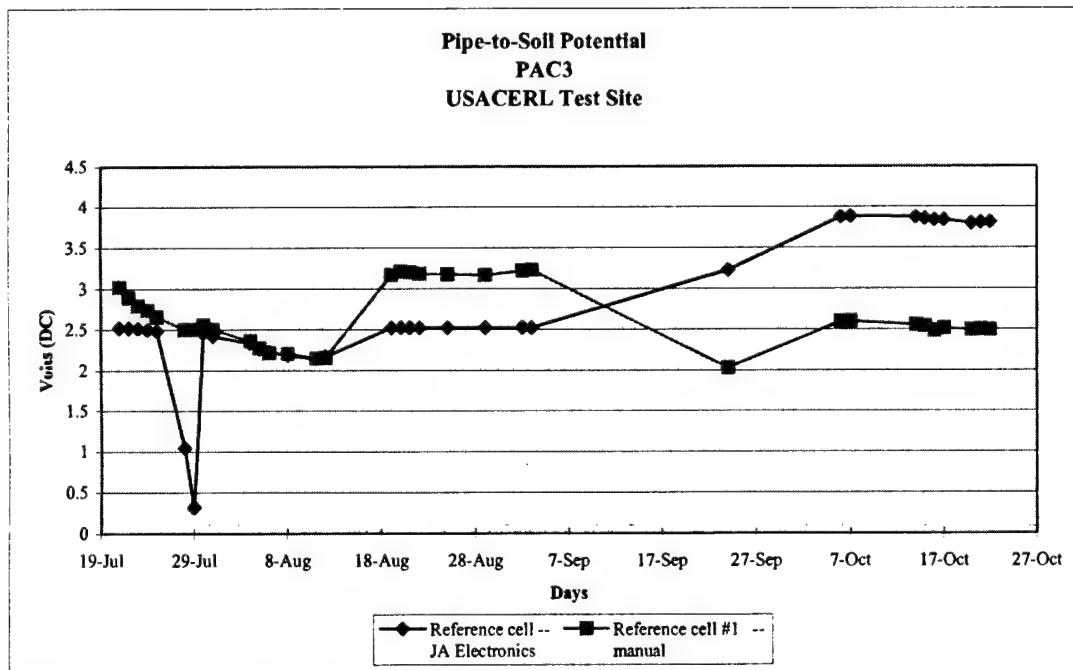

Figure 11. Pipe-to-soil "on" potential measured by JA Electronics PAC3 at USACERL test site.
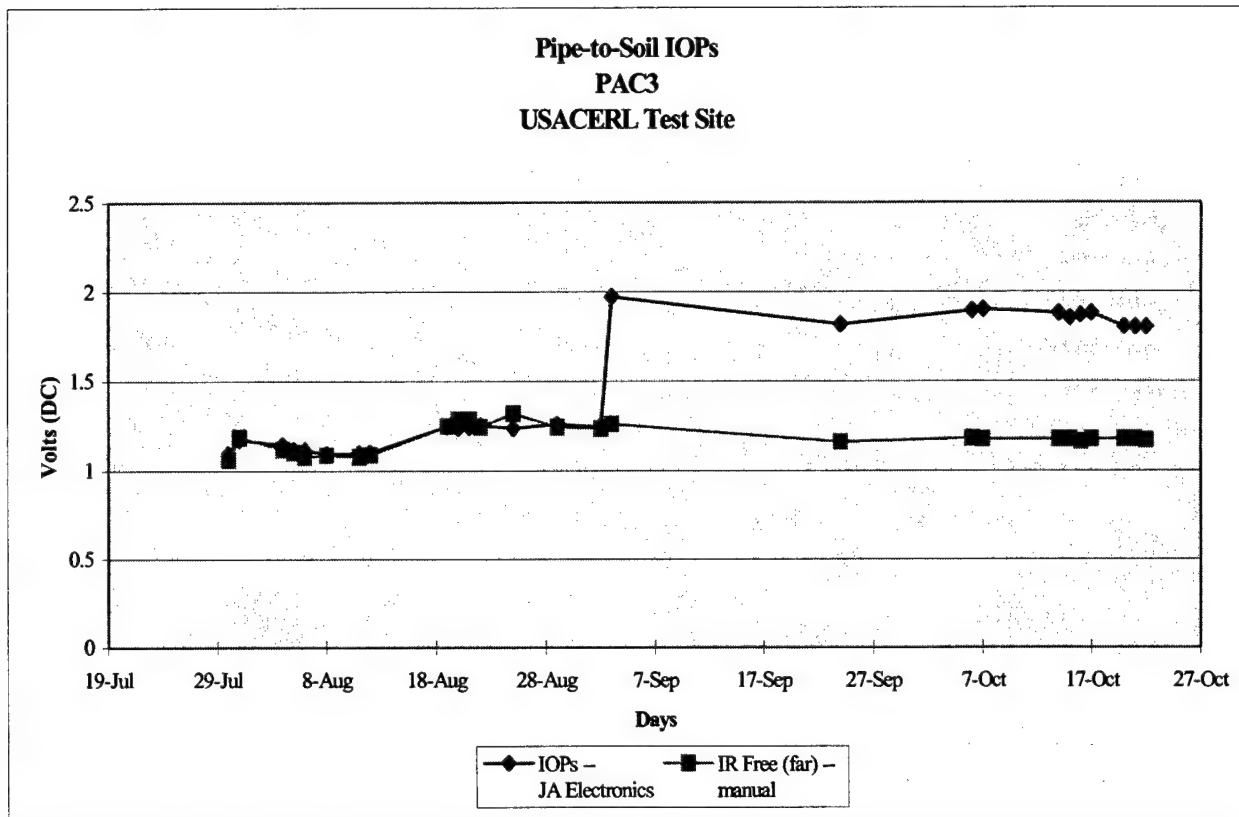
Figure 12. Pipe-to-soil "instant-off potentials" (IOPs) as measured by JA Electronics PAC3 at USACERL test site.

4 Conclusions and Recommendations

Conclusions

Five different commercially available remote monitoring systems for impressed current CP systems were field-tested at USACERL and Fort Drum during the two phases of this FEAP demonstration. The five systems were evaluated on the basis of measurement accuracy, hardware reliability and safety, quality of software, ease of hardware and software installation and configuration, and quality of instruction manuals. Shown in descending order, the final rankings were:

1. MC Miller DAX system
2. Metretek CPM II system
3. JA Electronics PAC3 system
4. Tomar Systems SMART system
5. Good-All RAMS system.

The MC Miller DAX is considered the best system overall in this evaluation due to its ease of installation and operation, its accuracy and reliability, and its overall flexibility and power.

The Metretek CPM II system was found to be operational and accurate during the demonstration. It is expected to provide accurate data and reliable service. It is a powerful system but is difficult to install and configure, especially for novice users.

The JA Electronics PAC3 system was found to be operational and fairly accurate during the demonstration, but it has limitations that may prevent it from being used in some locations. The software was extremely easy to install and configure. The hardware is attractive and well labeled, making installation simple.

Details of the Tomar SMART and Goodall RAMS unit evaluations are published in the Phase I report (FEAP TR 97/76/ADA328905). They were found to be

unacceptable for Army use when they were tested during 1996 (Van Blaricum et al. 1997).

Recommendations

It is recommended that three of the five units tested be considered adequate for Army use at this time:

1. MC Miller DAX
2. Metretek CPM II system
3. JA Electronics PAC3 system.

References

JA Electronics Manufacturing Co., Inc. *Cathodic Protection Remote Monitoring Systems* (Stafford, TX, February 1996).

Metretek, Inc., *Cathodic Protection Monitoring Software Installation* (Melbourne, FL, 1996).

Metretek, Inc. *Cathodic Protection Monitoring System Version 2.40 User's Guide* (Melbourne, FL, March 1996).

Metretek, Inc., *Metretek Cathodic Protection Monitor Model II Installation Manual* (Melbourne, FL, September 1996).

Metretek, Inc., *Metretek Power Interrupter Module* (Melbourne, FL, June 1996).

Metretek, Inc., *Metretek Programmer Hardware and Software Users Manual* (Melbourne, FL, September 1996).

Metretek, Inc., *Modular SMOD Installation Manual* (Melbourne, FL, February 1996).

Van Blaricum, Vicki L., William R. Norris, Michael J. Szeliga, and James B. Bushman, *Demonstration of Remote Monitoring Technology for Cathodic Protection Systems*, FEAP Technical Report 97/76 (U.S. Army Construction Engineering Research Laboratories, April 1997).

USACERL DISTRIBUTION

Chief of Engineers

ATTN: CEHEC-IM-LH (2)

ATTN: CEHEC-IM-LP (2)

ATTN: CECC-R

ATTN: CECW

ATTN: CECW-O

ATTN: CECW-P

ATTN: CECW-PR

ATTN: CEMP

ATTN: CEMP-E

ATTN: CERD-C

ATTN: CERD-ZA

ATTN: CERD-L

ATTN: CERD-M (2)

ASC (IM) 22060

ATTN: DAIM-FDP

CECPW 22310-3862

ATTN: CECPW-E

ATTN: CECPW-FT

ATTN: CECPW-ZC

US Army Engr District

ATTN: Library (42)

US Army Engr Division

ATTN: Library (8)

US Army Materiel Command (AMC)

Alexandria, VA 22333-0001

ATTN: AMCEN-F

ATTN: AMXEN-C 61299-7190

Installations: (20)

FORSCOM

Forts Gillem & McPherson 30330

ATTN: FCEN

Installations: (20)

TRADOC

Fort Monroe 23651

ATTN: ATBO-G

Installations: (20)

American Public Works Assoc. 64104-1806

US Gov't Printing Office 20401

ATTN: Rec Sec/Deposit Sec (2)

ATTN: DAIM-FDP Defense Tech Info Center 22060-6218

ATTN: CECPW-E ATTN: DTIC-O (2)

139

5/98